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TECHNICAL MEMORANDUM

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WIND-TUNNEL INVESTIGATION OF STATIC AERODYNAMIC CHARACTERISTICS OF A $\frac{1}{9}$-SCALE MODEL OF A POSSIBLE REENTRY CAPSULE AT MACH NUMBERS FROM 2.29 TO 4.65

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WIND-TUNNEL INVESTIGATION OF STATIC AERODYNAMIC CHARACTERISTICS OF A $\frac{1}{9}$- SCALE MODEL OF A POSSIBLE REENTRY CAPSULE AT MACH NUMBERS FROM 2.29 TO 4.65*

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SUMMARY

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An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the static aerodynamic characteristics of a $\frac{1}{9}$- scale model of a possible reentry capsule. Tests were performed both with and without an escape system attached to the exit face; two spherical-segment reentry faces (faces I and II) were also included as part of the investigation. Tests were performed at angles of attack from -4° to 184° and at Mach numbers from 2.29 to 4.65. The Reynolds numbers per foot varied from about 2.3×10^6 to 3.0×10^6.

The results show that the escape configuration trims with positive stability at an angle of attack near 180° (exit face forward) for all test Mach numbers. The capsule with face I and the capsule with face II both trim with positive stability near an angle of attack of 0° (reentry face forward). At Mach numbers of 4.65 and 3.94, however, the capsules are neutrally stable near an angle of attack of 180°. This condition is undesirable and proper precautions should be taken to ensure a satisfactory margin of instability for the configurations in this attitude.

INTRODUCTION

The development of a vehicle which may safely exit from and reenter the earth's atmosphere has been of increasing interest since the advent of unmanned satellites. Tests have been made on two nonlifting shapes at several facilities through a Mach number range from subsonic to hypersonic speeds and at various Reynolds numbers. (One of these tests is described in ref. 1.) These two shapes were designed to employ the heat-sink concept for safe reentry into the earth's atmosphere. As a result of these tests, a new shape was designed. Incorporated in this design is an escape rocket system which was added to the exit face. The function of this escape system is to separate the vehicle from the booster rocket in case the booster malfunctions before or during the exit phase of flight. Once the

*Title, Unclassified.

vehicle has safely exited from the atmosphere, the escape system would then be jettisoned. Two stability requirements for the vehicle are: (1) When the escape system is attached the vehicle must trim with positive stability only when the escape system is forward, and (2) when the escape system is jettisoned the vehicle must trim with positive stability only when the reentry face is forward.

Since the modifications to the model tested in reference 1 were rather extensive, it was felt that wind-tunnel tests on the revised model were necessary in order to determine if the stability requirements were satisfied. The National Aeronautics and Space Administration has initiated a program to determine the stability characteristics of the revised vehicle during both the exit and reentry phases of flight. As a part of this program, tests have been conducted at the Langley Unitary Plan wind tunnel on the capsule with and without the escape system at Mach numbers from 2.29 to 4.65 and at Reynolds numbers per foot from approximately 2.3×10^6 to 3.0×10^6. Tests extended over an angle-of-attack range from -4° to 184°.

SYMBOLS

The aerodynamic force and moment data are referred to the body axes system with the origin at the center of gravity (fig. 1). The symbols used are defined as follows:

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

$C_{A,\alpha\approx 0^\circ}$ axial-force coefficient at $\alpha \approx 0^\circ$

$C_{A,c}$ chamber axial-force coefficient, $\frac{\text{Chamber axial force}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSd}$

C_{m_α} slope of pitching-moment coefficient at $\alpha \approx 0^\circ$, $\frac{\partial C_m}{\partial \alpha}$ per deg

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS}$

C_{N_α} slope of normal-force coefficient at $\alpha \approx 0^\circ$, $\frac{\partial C_N}{\partial \alpha}$ per deg

d	maximum body diameter, 10.640 in.
M	free-stream Mach number
q	free-stream dynamic pressure, lb/sq ft
R	Reynolds number per foot
S	maximum cross-sectional area, sq ft
T_t	stagnation temperature, $^{\circ}F$
α	angle of attack of model center line ($\alpha = 0^{\circ}$ when reentry face is forward, fig. 2), deg

APPARATUS AND METHODS

Tunnel

Tests were conducted in the high Mach number test section of the Langley Unitary Plan wind tunnel which is a variable-pressure continuous-flow tunnel. The nozzle leading to the test section is of the asymmetric sliding-block type which permits a continuous variation in test-section Mach number from approximately 2.3 to 4.7.

Models

All pertinent dimensions of the 1/9-scale model are shown in figure 2. Photographs of the models are presented in figure 3. The models were constructed of plastic, fiber glass, and stainless steel and were built by the NASA.

The model was tested both with and without the escape system attached. The escape configuration incorporates a rocket mounted on three braces to the exit face of the capsule as shown in figure 2. Two different spherical-segment reentry faces were also tested. Henceforth, the models will be referred to as the capsule with face I, the capsule with face II, and the escape configuration (capsule with face I, rocket, and rocket braces).

Test Conditions

Tests were performed at the following conditions:

M	R	T_t, °F	Angle-of-attack range, deg		
			Capsule with face I	Capsule with face II	Escape configuration
4.65	2.3×10^6	175	-4 to 184	-4 to 83	150 to 184
3.94	2.5	175			
2.97	2.8	150			
2.29	3.0	150			

In order to obtain an angle-of-attack range from -4° to 184°, four separate sting-supported arrangements were required. Photographs of these arrangements are presented in figure 3 (from -4° to 83°α the reentry face is forward and from 98° to 184°α the exit face is forward).

The dewpoint, measured at stagnation pressure, was maintained below -30° F for all tests in order to assure negligible condensation effects. All tests were conducted with natural boundary-layer transiton.

Measurements

Aerodynamic forces and moments were measured by means of an electrical strain-gage balance housed within the model. The balance, in turn, was rigidly fastened to a sting support system. Balance-chamber pressure was measured with a single static orifice located in the balance cavity. Schlieren photographs were taken at various model attitudes, Mach numbers, and Reynolds numbers.

Accuracy

Based upon balance calibration and repeatability of data, it is estimated that the various measured quantities are accurate within the following limits:

C_A . . . . ±0.020
$C_{A,c}$ . . . . ±0.001
C_m . . . . ±0.005
C_N . . . . ±0.020
M . . . . ±0.05
α, deg . . . . ±0.10

Corrections

Angles of attack have been corrected for both tunnel flow angularity and deflection of balance and sting system due to aerodynamic loads. Measured pressure gradients within the test section indicate that buoyancy effects are negligible.

The axial-force coefficients presented are gross values. Chamber axial force, however, has been determined and is presented in figures 4(a) and 4(b).

DISCUSSION

Pitching Moment

The data presented in figure 5 show that the escape configuration trims with positive stability at an angle of attack near 180° throughout the test Mach number range and therefore from a static-stability standpoint, this configuration is acceptable. An interesting point noted in figure 5 is the break in the pitching-moment curve that occurs near an angle of attack of 177° at Mach numbers of 2.97 and 2.29. This same phenomenon occurred at a comparable angle of attack for this configuration tested in combination with a booster rocket (data unpublished). The break is attributed to the flow pattern created by the escape system since this break did not occur when the rocket was removed. (See fig. 6(a) at $\alpha \approx 180^{\circ}$.)

The capsule with face I and the capsule with face II both trim with positive stability near an angle of attack of 0° at all test Mach numbers as may be seen in figures 6(a) and 6(b). Figure 6(a) also shows that at Mach numbers of 4.65 and 3.94, the capsule with face I is neutrally stable near an angle of attack of 180°. It is believed that the same trend will occur for the capsule with face II. This condition is undesirable since the reentry face of the vehicle must be forward for safe reentry; proper precautions should be taken to ensure a satisfactory margin of instability at this attitude. From a static-stability standpoint, the results indicate that in the Mach number range tested, the capsule with either face I or face II can successfully be used as a reentry vehicle provided the aforementioned precautions are considered. Figures 6(a) and 6(b) show a discontinuity in the pitching-moment curves at angles of attack between about 30° and 47°. This phenomenon may be attributed to the rearward portion of the model emerging from a low q region to a high q region thus producing increased pitching moments at the higher angles of attack. Schlieren photographs indicating this phenomenon may be found in figure 7. (See photographs for $\alpha \approx 30^{\circ}$ and $\alpha \approx 47^{\circ}$.)

The stability parameter C_{m_α} is essentially the same for the two reentry configurations throughout the test Mach number range (fig. 8) and the increase in longitudinal stability with Mach number may be noted. At Mach numbers above 4.0, C_{m_α} is essentially constant.

Axial Force and Normal Force

Throughout the test Mach number range, the axial-force coefficients of the capsule with face I near an angle of attack of 0° are slightly less than those of the capsule with face II (fig. 8). For each model, $C_{A,\alpha \approx 0^\circ}$ is approximately constant throughout the test Mach number range. The normal-force slopes of the capsule with face I are slightly greater than those of the capsule with face II and the slopes for both configurations increase with an increase in Mach numbers up to about 4.0. At Mach numbers above 4.0, C_{N_α} is essentially constant.

CONCLUSIONS

A wind-tunnel investigation has been conducted to determine the static aerodynamic characteristics of a $\frac{1}{9}$-scale model of a possible reentry capsule. Tests were performed both with and without an escape system attached to the exit face; two spherical-segment reentry faces (faces I and II) were included as part of the investigation. The results of these tests indicate the following conclusions:

1. The escape configuration trims with positive stability at an angle of attack near 180° for all test Mach numbers.

2. The capsule with face I and the capsule with face II both trim with positive stability near an angle of attack of 0°. At Mach numbers of 4.65 and 3.94, however, the capsules are neutrally stable near an angle of attack of 180°. This latter condition is undesirable and proper precautions should be taken to ensure a satisfactory margin of instability for the configurations in this attitude.

3. The effect on the aerodynamic characteristics of changing the reentry face from face I to face II was slight.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 17, 1959.

REFERENCE

1. Turner, Kenneth L., and Shaw, David S.: Wind-Tunnel Investigation at Mach Numbers From 1.60 to 4.50 of the Static-Stability Characteristics of Two Nonlifting Vehicles Suitable for Reentry. NASA MEMO 3-2-59L, 1959.

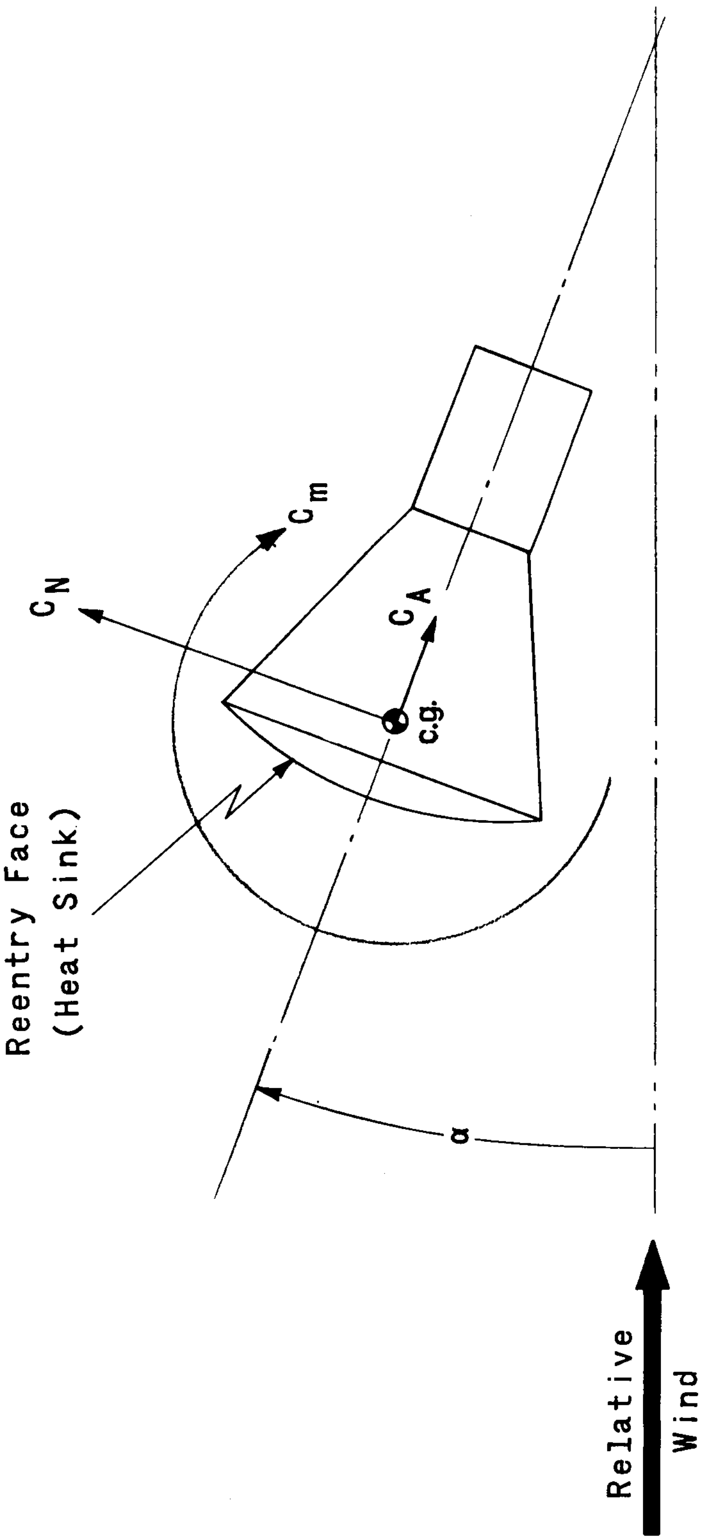


Figure 1.- Body axes system. (Arrows indicate positive direction.)

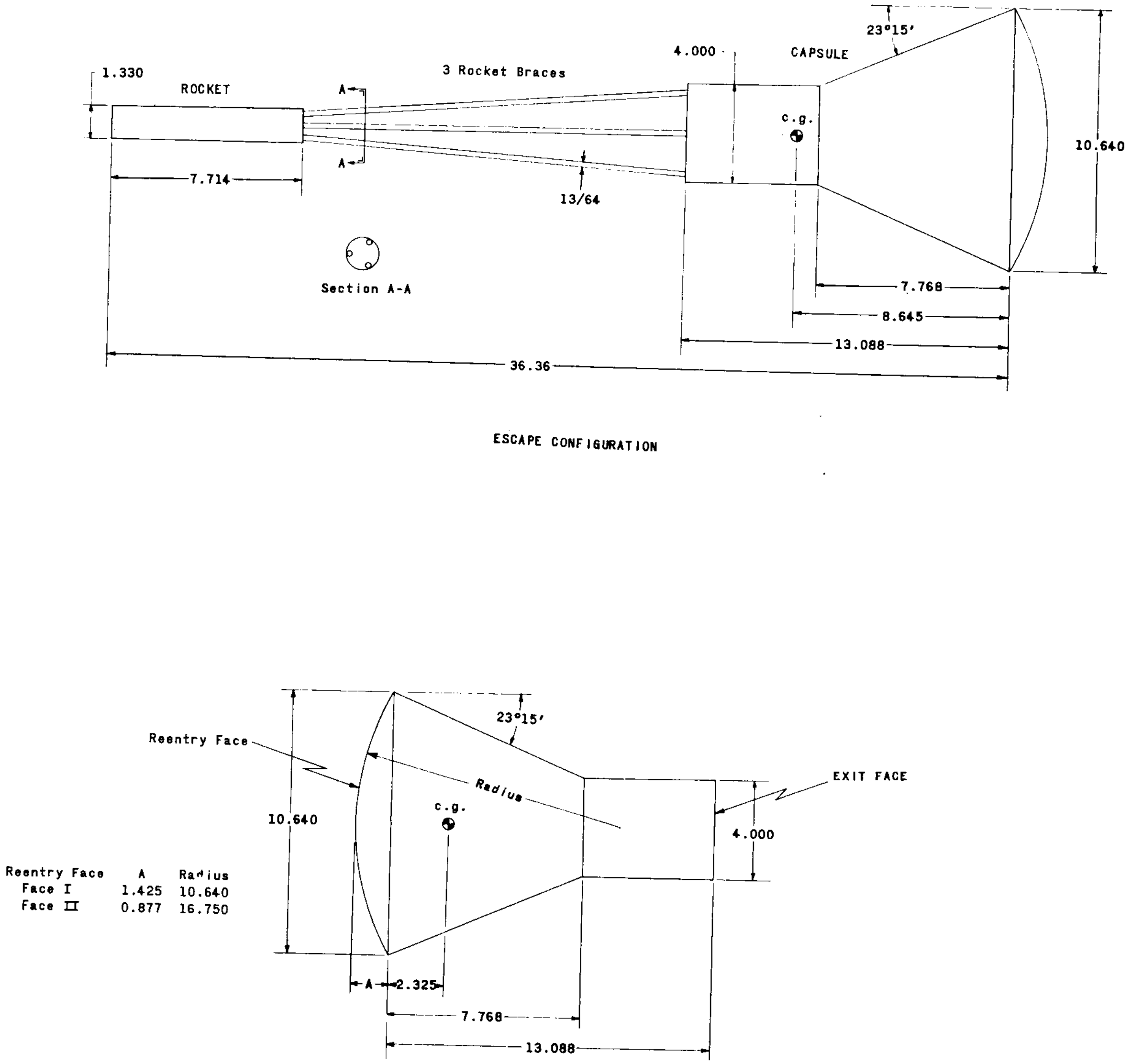
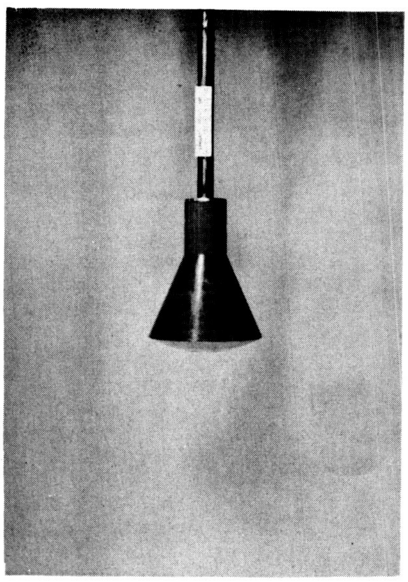


Figure 2.- Drawings and dimensions of models. (All dimensions are in inches unless otherwise noted.)



α = -4° to 31°

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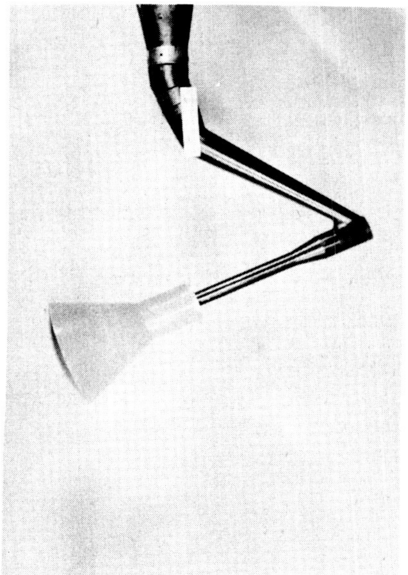
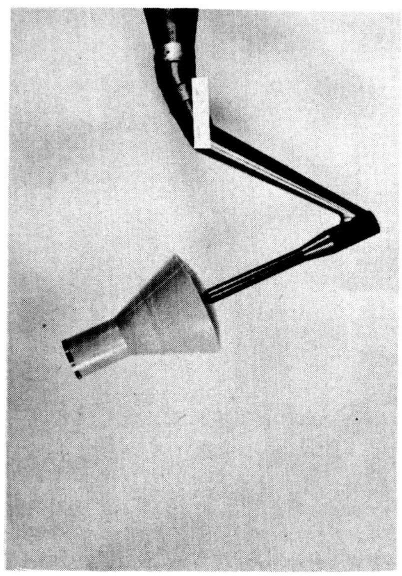


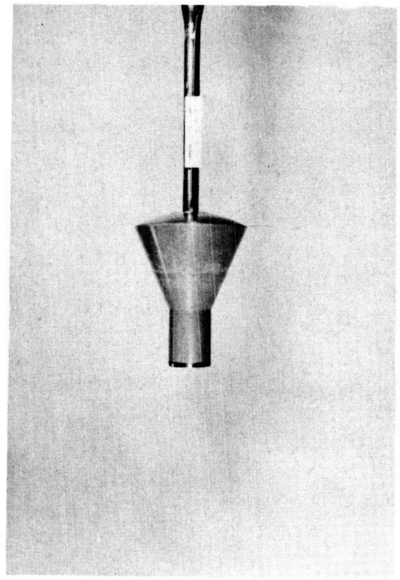
α = 47° to 83°

L-59-144



α = 98° to 133°

L-59-142

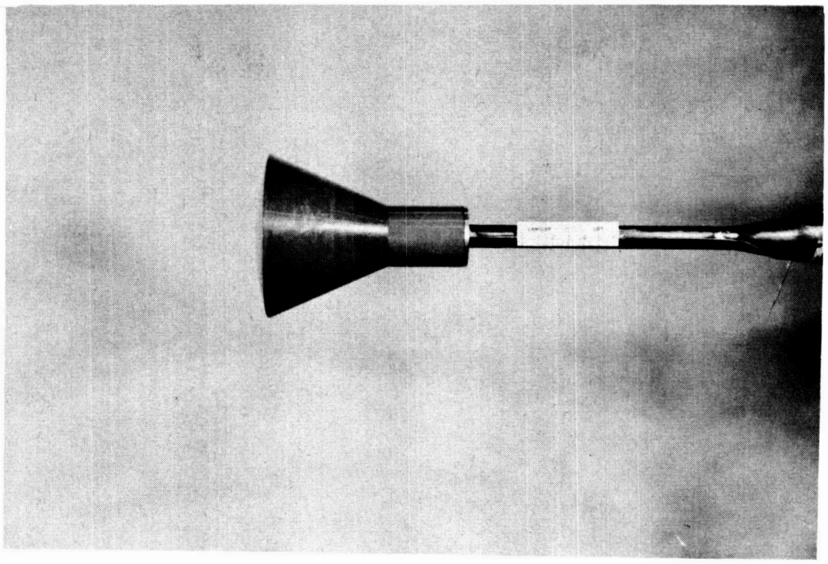


α = 148° to 184°

L-59-148

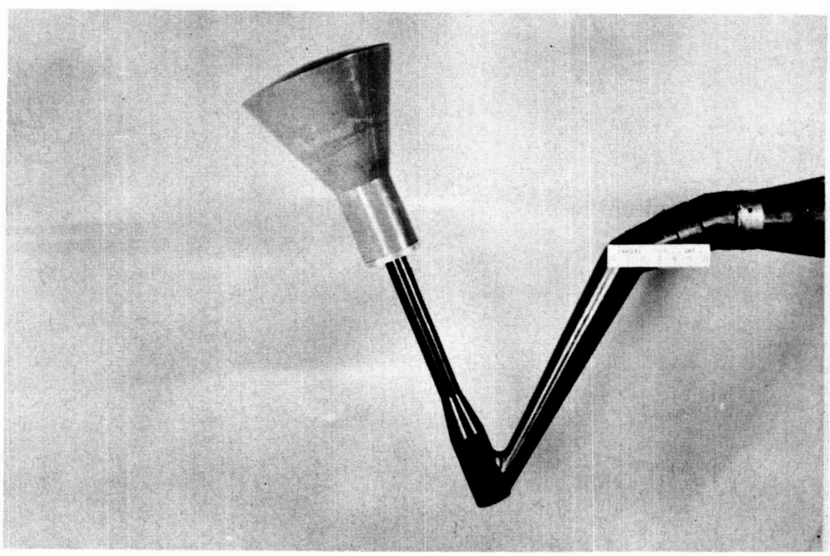
(a) Capsule with face I.

Figure 3.- Sting-support arrangements.



α = -4° to 32°

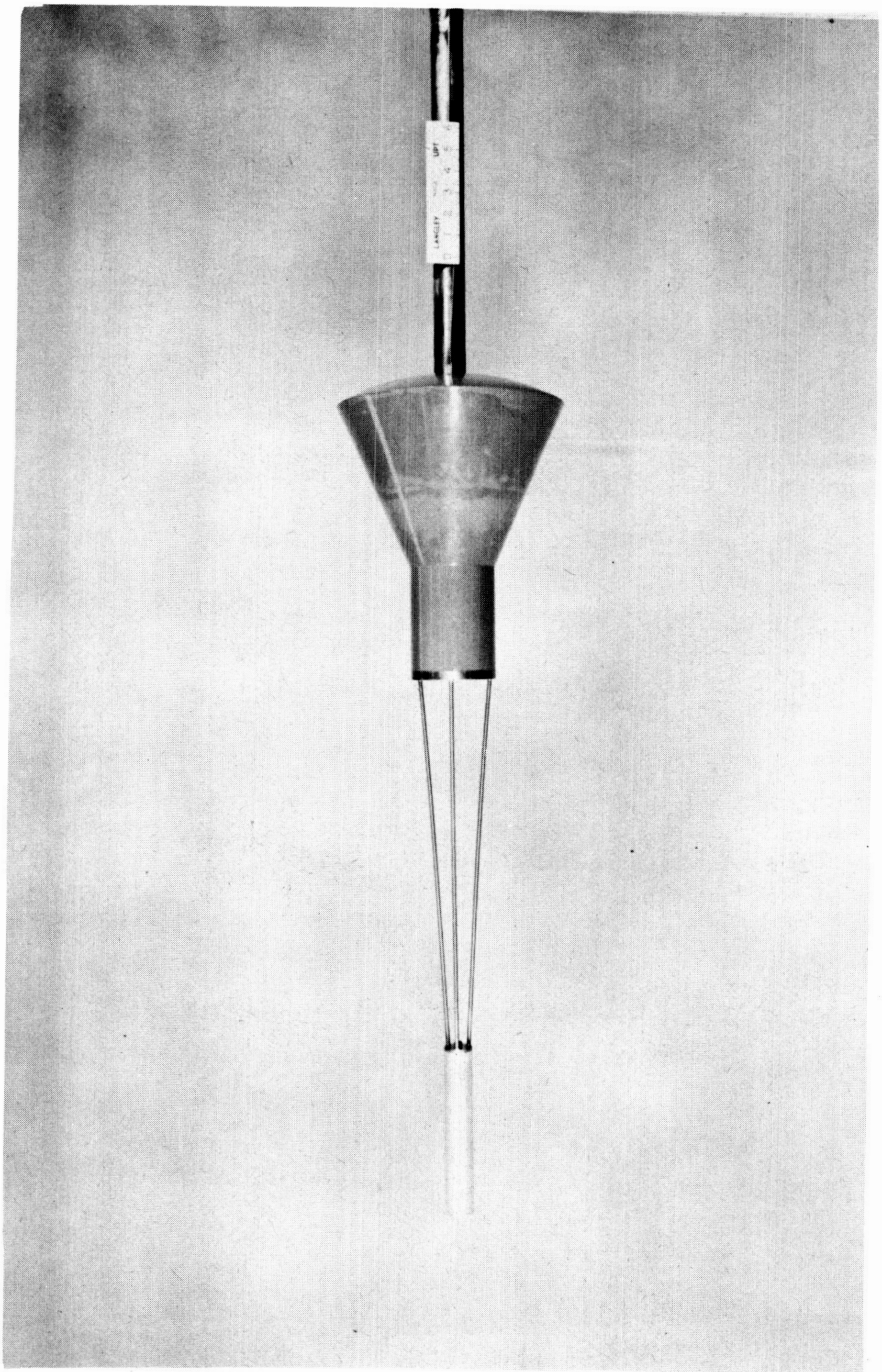
L-59-147



α = 49° to 83°

(b) Capsule with face II. L-59-143

Figure 3.- Continued.



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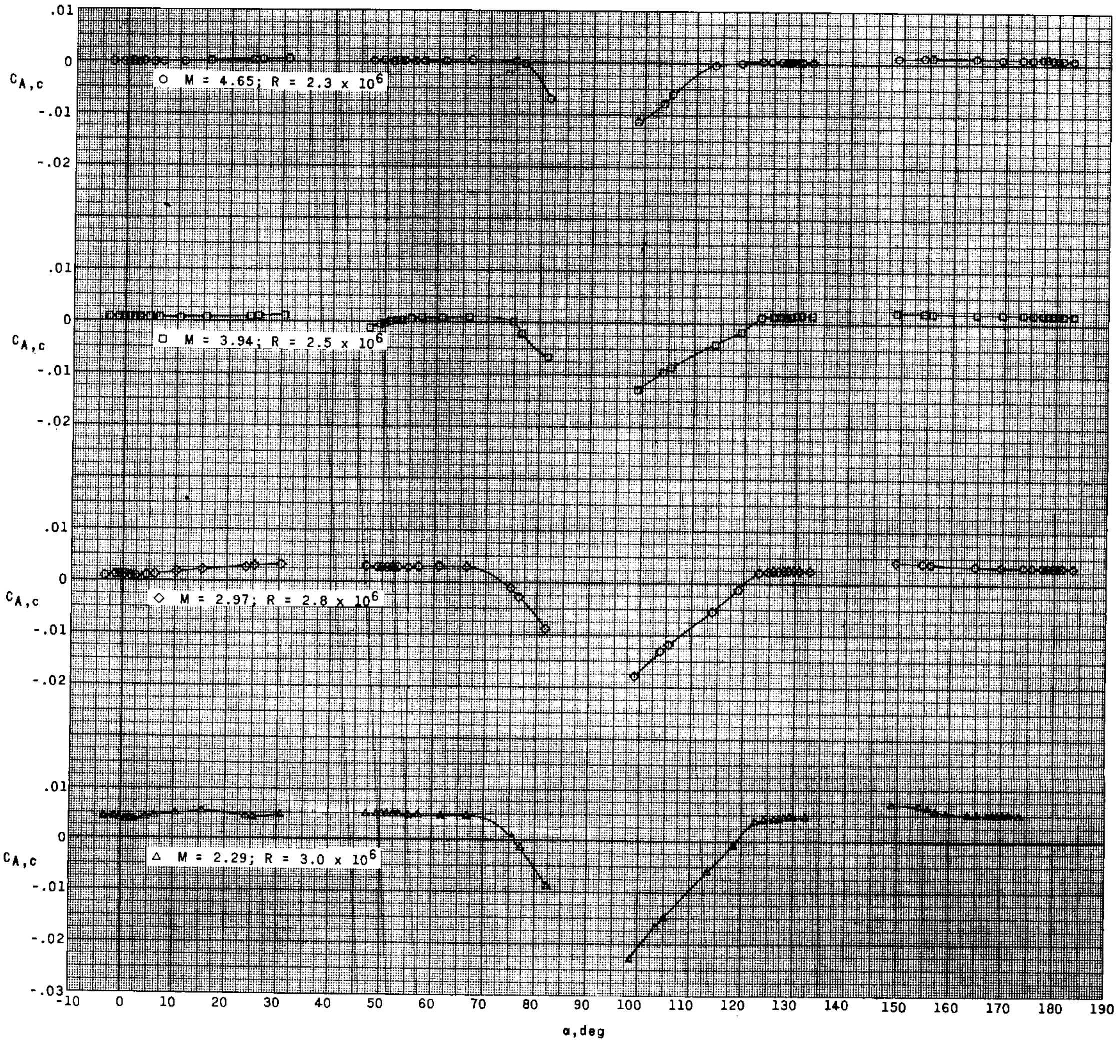
$\alpha = 153^\circ$ to 184°

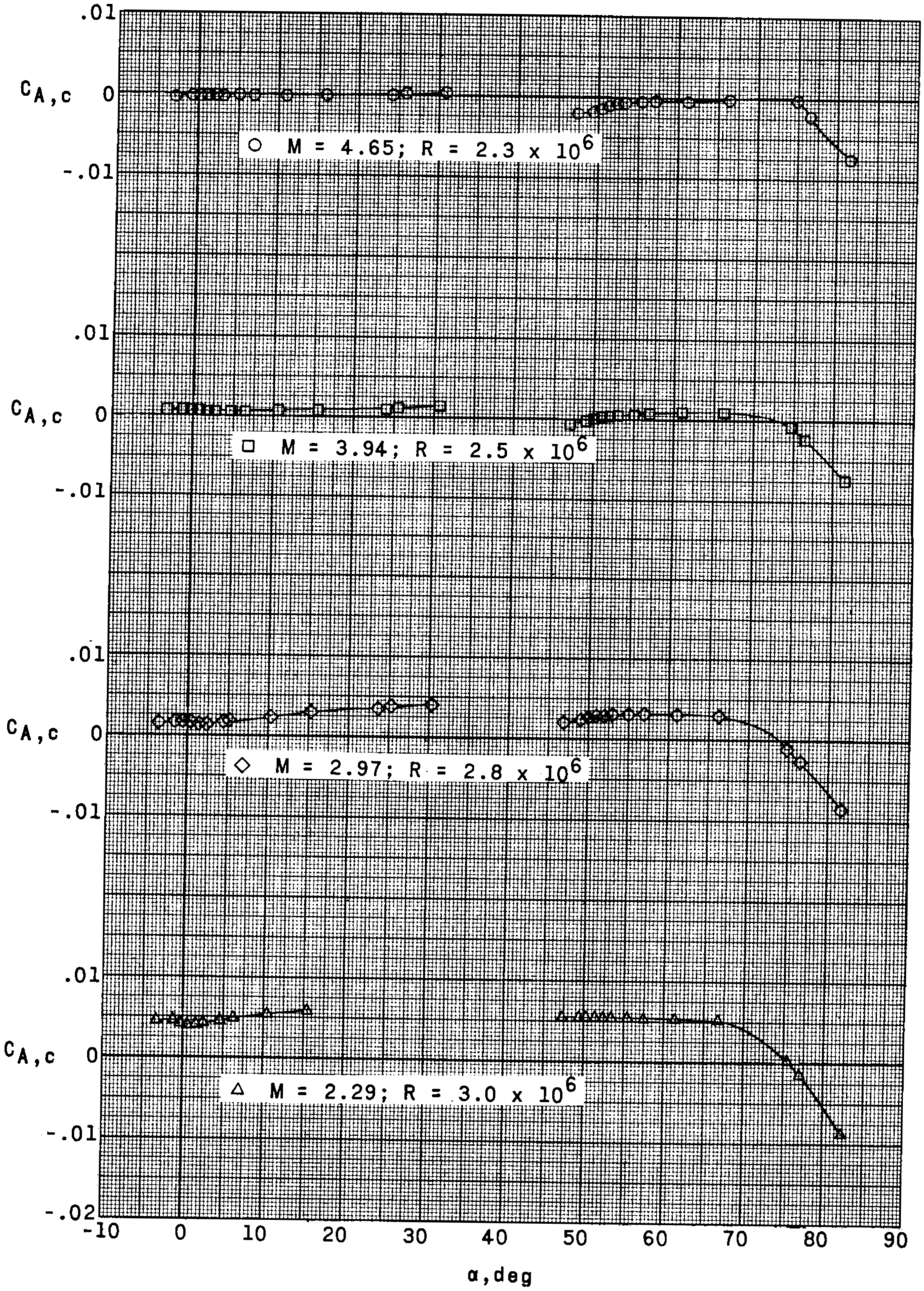
(c) Escape configuration.

Figure 3.- Concluded.



(a) Capsule with face I.

Figure 4.- Chamber axial-force coefficients.



(b) Capsule with face II.

Figure 4.- Concluded.

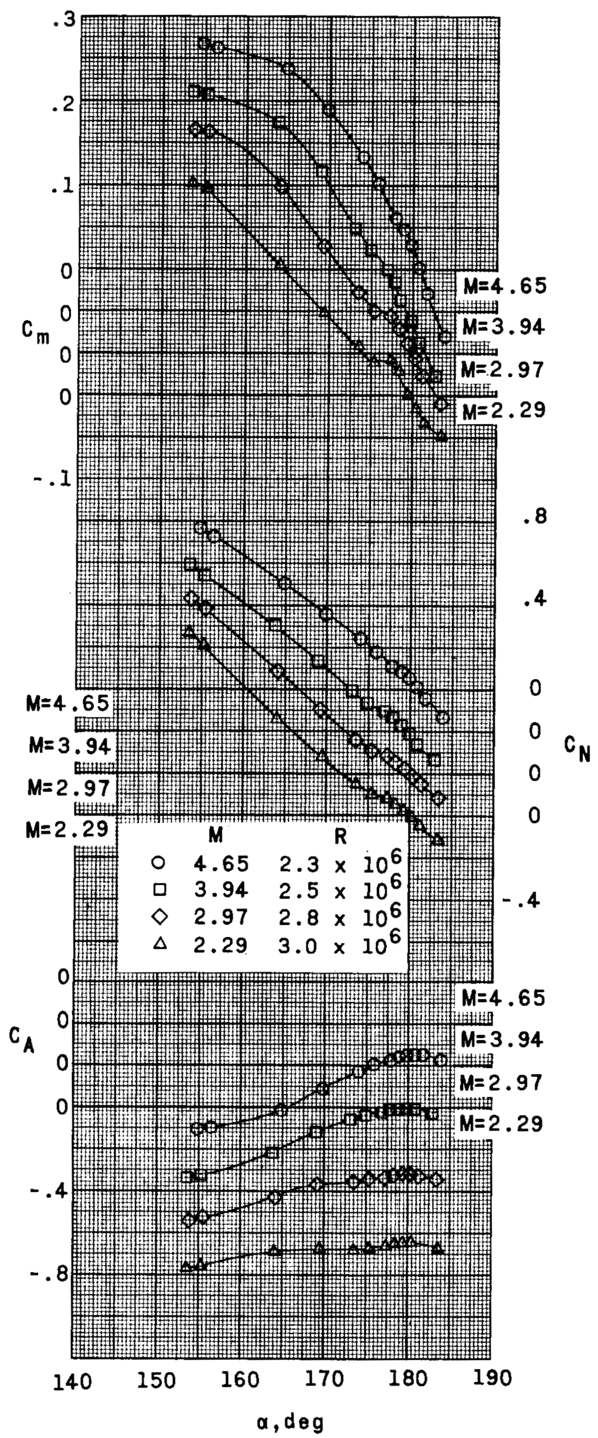
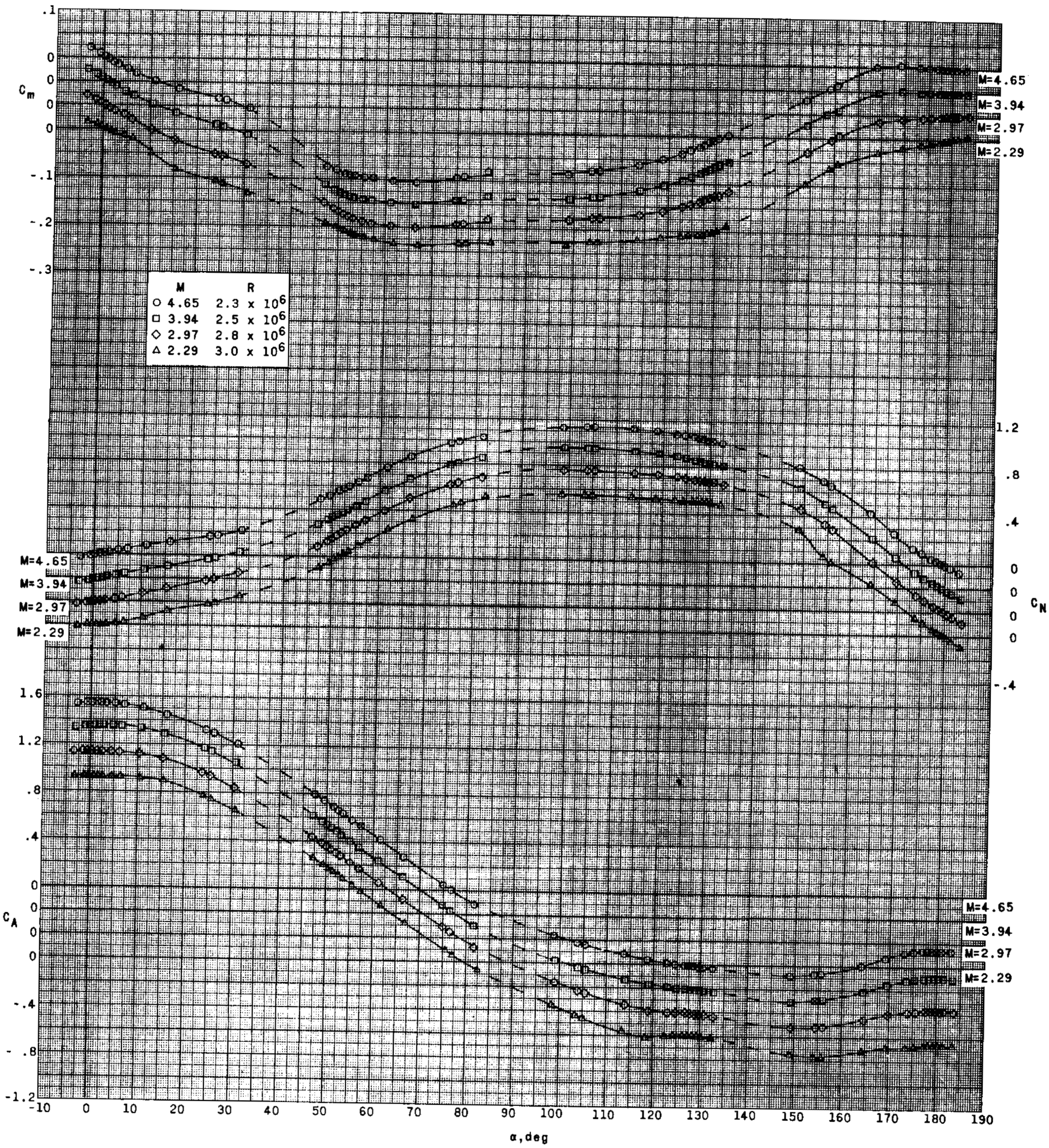
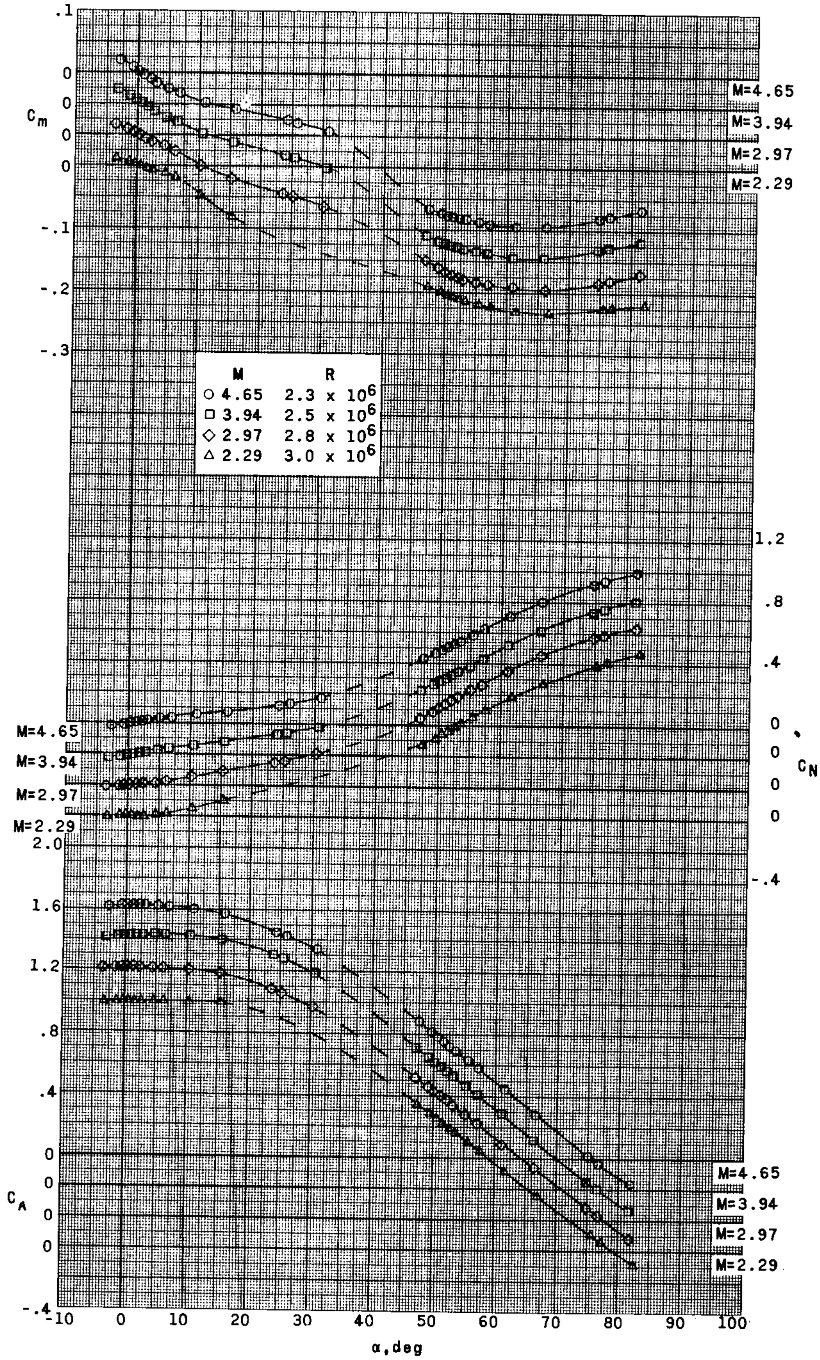


Figure 5.- Aerodynamic characteristics of escape configuration in pitch.



(a) Capsule with face I.

Figure 6.- Aerodynamic characteristics of capsule in pitch.



(b) Capsule with face II.

Figure 6.- Concluded.

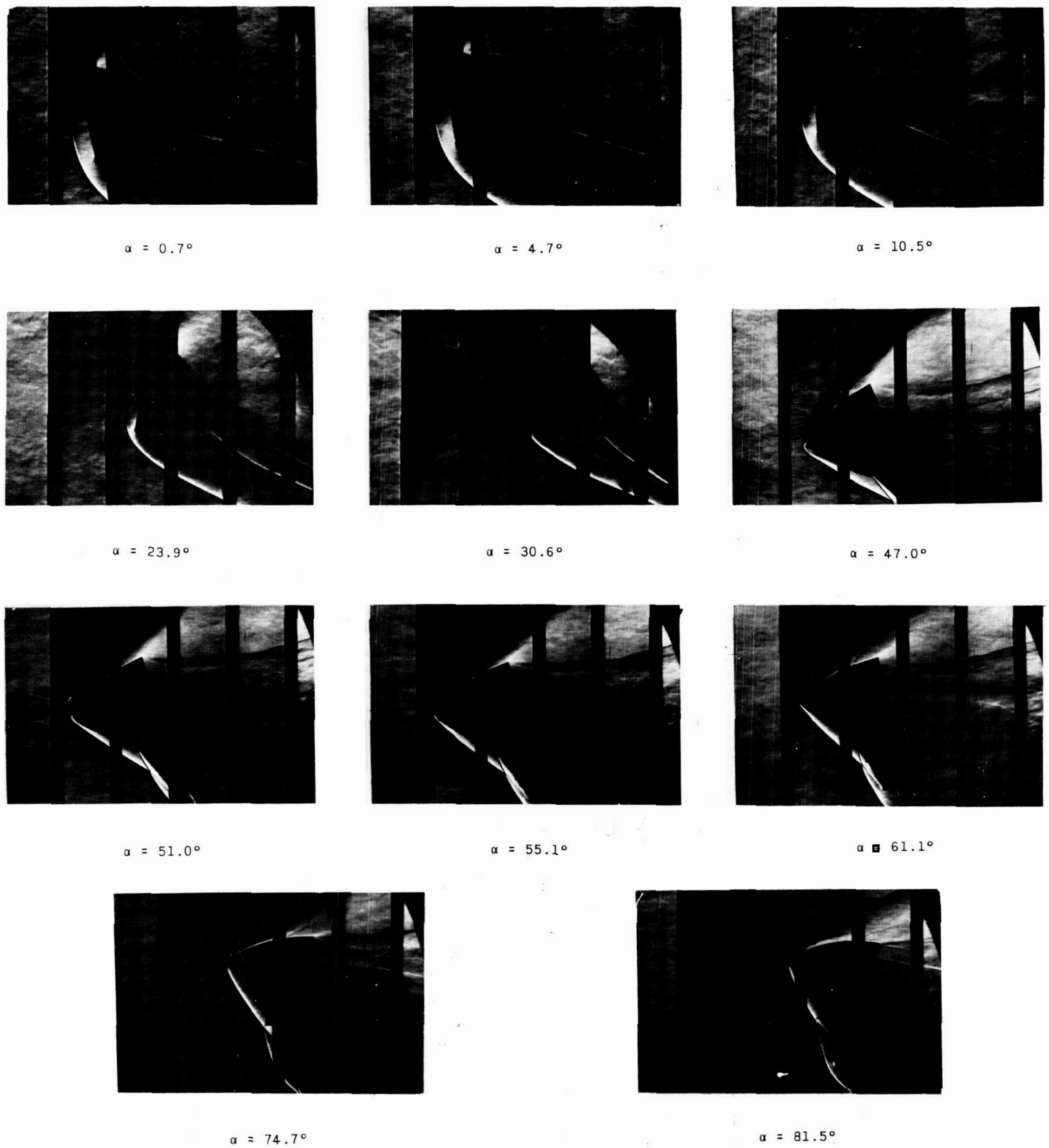


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Figure 7.- Typical schlieren photographs of capsule with face II. $M = 3.94$; $R = 2.5 \times 10^6$.

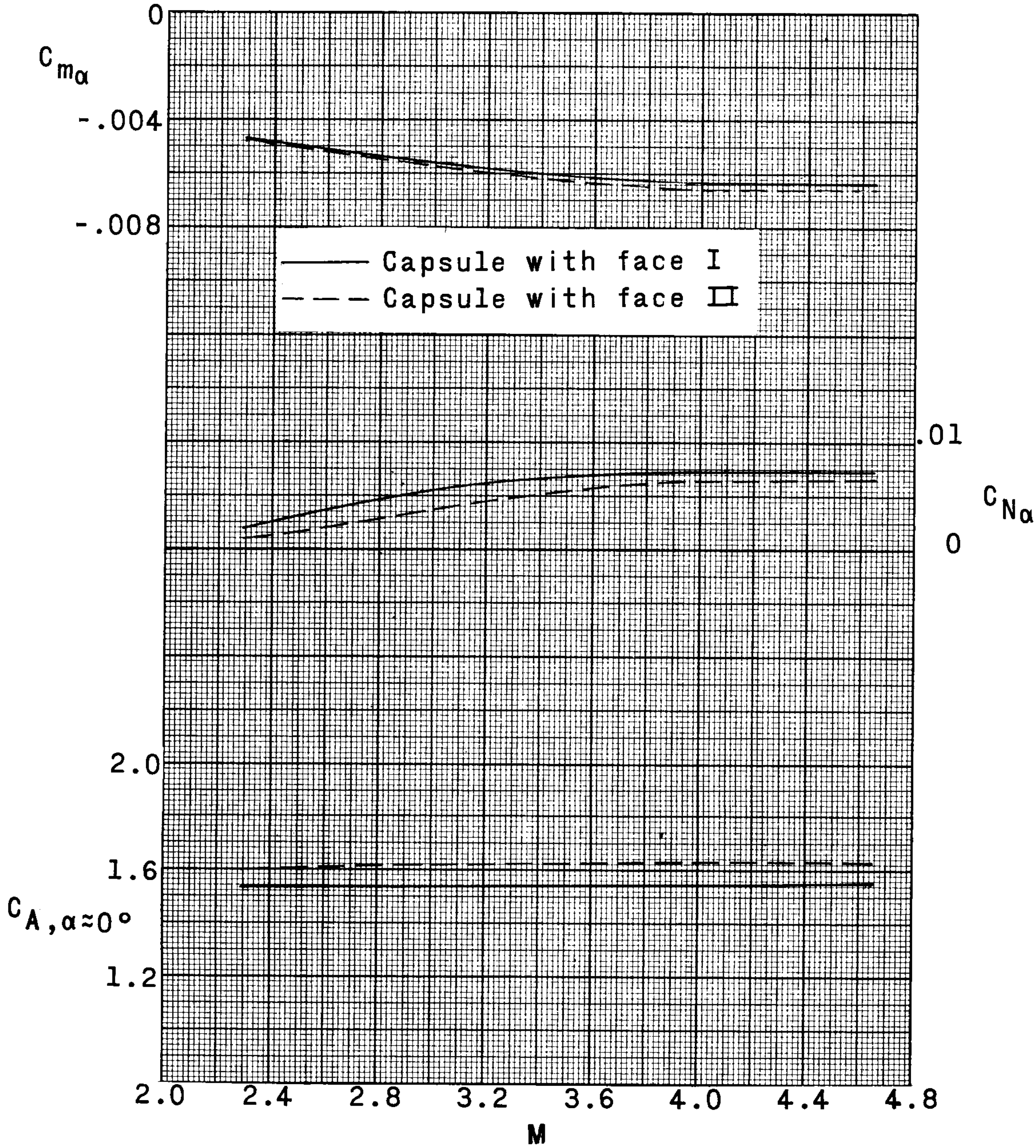

Figure 8.- Summary of stability and axial-force characteristics of capsule with face I and capsule with face II.